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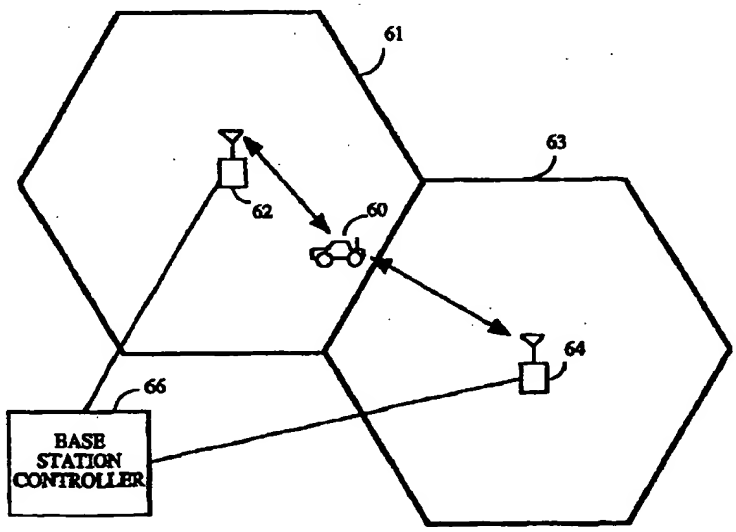
(54) Title: MOBILE STATION ASSISTED TIMING SYNCHRONIZATION IN A CDMA COMMUNICATION SYSTEM

(57) Abstract

In the present invention, the slave base station (64) attains synchronization with the reference base station (62) through messages transmitted from and received by a mobile station (60) in the soft handoff region between the reference base station (62) and the slave base station (64). First, the round trip delay between the mobile station (60) and the reference base station (62) is measured by the reference base station (62). Once the mobile station (60) acquires the signal from the slave base station (64), it measures and reports the difference between the amount of time it takes a signal to travel from the reference base station (62) to it and the amount of time it takes a signal to travel from the slave base station (64) to it. The last measurement necessary is a measurement by the slave base station (64) of the time difference between the time it received the reverse link signal from the mobile (60) and station the time it transmitted a signal to the mobile station. A series of computations described in detail herein are performed upon the measured time values to determine the time difference between the slave base station (64) and an adjustment o f the slave base station (64) timing is performed in accordance therewith.



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MOBILE STATION ASSISTED TIMING SYNCHRONIZATION IN A CDMA COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to communication systems. More particularly, the present invention relates to a novel and improved method and apparatus for synchronizing a base station by means of signals transmitted from a mobile station which is concurrently in communication with a synchronized base station.

II. Description of the Related Art

The use of code division multiple access (CDMA) modulation techniques is but one of several techniques for facilitating communications in which a large number of system users are present. Although other techniques, such as time division multiple access (TDMA), frequency division multiple access (FDMA) and AM modulation schemes such as amplitude companded single sideband (ACSSB) are known, CDMA has significant advantages over these other modulation techniques. The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS" and U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM", both of which are assigned to the assignee of the present invention and are incorporated by reference. The method for providing CDMA mobile communications was standardized in the United States by the Telecommunications Industry Association in TIA/EIA/IS-95-A entitled "Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System", referred to herein as IS-95.

In the just mentioned patents, a multiple access technique is disclosed in which a large number of mobile station users, each having a transceiver, communicate through satellite repeaters or terrestrial base stations (also known as cell base stations or cell-sites) using code division multiple access (CDMA) spread spectrum communication signals. By using CDMA communications, the frequency spectrum can be reused multiple times thus

permitting an increase in system user capacity. The use of CDMA techniques result in much higher spectral efficiency than can be achieved using other multiple access techniques.

A method for simultaneously demodulating data that has traveled along different propagation paths from one base station and for simultaneously demodulating data redundantly provided from more than one base station is disclosed in U.S. Patent No. 5,109,390 (the '390 patent), entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR COMMUNICATION SYSTEM", assigned to the assignee of the present invention and incorporated by reference herein. In the '390 patent, the separately demodulated signals are combined to provide an estimate of the transmitted data which has higher reliability than the data demodulated by any one path or from any one base station.

Handoffs can generally be divided into two categories- hard handoffs and soft handoffs. In a hard handoff, when a mobile station leaves an origination base station and enters a destination base station, the mobile station breaks its communication link with the origination base station and thereafter establishes a new communication link with the destination base station. In soft handoff, the mobile station completes a communication link with the destination base station prior to breaking its communication link with the origination base station. Thus, in soft handoff, the mobile station is redundantly in communication with both the origination base station and the destination base station for some period of time.

Soft handoffs are far less likely to drop calls than hard handoffs. In addition, when a mobile station travels near the coverage boundary of a base station, it may make repeated handoff requests in response to small changes in the environment. This problem, referred to as ping-ponging, is also greatly lessened by soft handoff. The process for performing soft handoff is described in detail in U.S. Patent No. 5,101,501, entitled "METHOD AND SYSTEM FOR PROVIDING A SOFT HANDOFF IN COMMUNICATIONS IN A CDMA CELLULAR TELEPHONE SYSTEM" assigned to the assignee of the present invention and incorporated by reference herein.

An improved soft handoff technique is disclosed in U.S. Patent No. 5,267,261, entitled "MOBILE STATION ASSISTED SOFT HANDOFF IN A CDMA CELLULAR COMMUNICATIONS SYSTEM", which is assigned to the assignee of the present invention and incorporated by reference herein. In the system of the '261 patent, the soft handoff process is improved by measuring the strength of "pilot" signals transmitted by each base station at the mobile station. These pilot strength measurements are of assistance in

the soft handoff process by facilitating identification of viable base station handoff candidates.

The base station candidates can be divided into four sets. The first set, referred to as the Active Set, comprises base stations which are currently in communication with the mobile station. The second set, referred to as the Candidate Set, comprises base stations whose signals have been determined to be of sufficient strength to be of use to the mobile station but are not currently being used. Base stations are added to the candidate set when their measured pilot energy exceeds a predetermined threshold T_{ADD}. The third set is the set of base stations which are in the vicinity of the mobile station (and which are not included in the Active Set or the Candidate Set). And the fourth set is the Remaining Set which consists of all other base stations.

In IS-95, a base station candidate is characterized by the phase offset of the pseudonoise (PN) sequence of its pilot channel. When the mobile station searches to determine the strength of the pilot signal from a candidate base station it performs a correlation operation wherein the filtered received signal is correlated to a set of PN offset hypotheses. The method and apparatus for performing the correlation operation is described in detail in co-pending U.S. Patent Application Serial No. 08/687,694, filed on July 26, 1996, entitled "METHOD AND APPARATUS FOR PERFORMING SEARCH ACQUISITION IN A CDMA COMMUNICATION SYSTEM", which is assigned to the assignee of the present invention and incorporated by reference herein.

The propagation delay between the base station and the mobile station is not known. This unknown delay produces and unknown shift in the PN codes. The searching process attempts to determine the unknown shift in the PN codes. To do this, the mobile station shifts in time the output of its searcher PN code generators. The range of the search shift is called the search window. The search window is centered about a PN shift hypothesis. A base station transmits to the mobile station a message indicating the PN offsets of base station pilots in its physical proximity. The mobile station will center its search window around the PN offset hypothesis.

The appropriate size of the search window depends on several factors including the priority of the pilot, the speed of the searching processors, and the anticipated delay spread of the multipath arrivals. The CDMA standards (IS-95) define three search window parameters. The searching of pilots in both the active and candidate sets is governed by Search Window "A". Neighbor Set pilots are searched over window "N" and Remaining Set

pilots over window "R". The searcher window sizes are provided below in Table 1, where a chip is $\frac{1}{1.2288\,MHz}$.

SRCH_WIN_A SRCH_WIN_N SRCH_WIN_R	Window Size (PN chips)	SRCH_WIN_A SRCH_WIN_N SRCH_WIN_R	Window Size (PN chips)
0	4	8	60
1	6	9	80
2	8	10	100
3	10	11	130
4	14	12	160
5	20	13	226
6	28	14	320
7	40	15	452

TABLE 1

Window sizing is a trade-off between search speed and the probability of missing a strong path lying outside the search window.

The base station transmits to the mobile station a message which specifies the PN hypotheses that the mobile station should search relative to its own PN offset. For example, the originating base station may instruct the mobile station to search for a pilot 128 PN chips ahead of its own PN offset. The mobile station in response sets its searcher demodulator 128 chips ahead in the output chip cycle and searches for the pilot using a search window centered about the specified offset. Once the mobile is instructed to a search a PN hypothesis to determine the resources available for performing a handoff, it is critical that the PN offset of the destination base station pilot is very close in time to the directed offset. The speed of searching is of critical importance near base station boundaries because delays in completing the necessary searches can result in dropped calls.

In CDMA systems in the United States, this base station synchronization is achieved by providing each base station with a Global Positioning Satellite (GPS) receiver. However, there are cases where a base station may not be able to receive the GPS signal. For example, within subways and tunnels the GPS signal is attenuated to a degree that prohibits their use for timing synchronization of base stations or micro base stations. The present invention provides a method and system for providing timing synchronization in these circumstances where a fraction of the network is

capable of receiving a centralized timing signal and achieving timing therefrom and a portion of the base stations are not capable of receiving the centralized timing signal.

SUMMARY OF THE INVENTION

The present invention is a novel and improved method and apparatus for time synchronizing a base station which is not capable of receiving a centralized timing signal in a network where some of the base stations are capable of receiving the centralized timing signal. The reference base station has timing synchronization through receipt of a centralized timing signal or other means. In the exemplary embodiment, the reference base station synchronizes using a global positioning satellite (GPS) receiver. The slave base station lacks the capacity to synchronize, because for example of an inability to receive the centralized timing signal.

In the present invention, the slave base station attains synchronization with the reference base station through messages transmitted from and received by a mobile station in the soft handoff region between the reference base station and the slave base station. First, the round trip delay between the mobile station and the reference base station is measured by the reference base station. Next, the slave base station searches until it acquires the signal transmitted by the mobile station, referred to as the reverse link signal. In response to the acquisition of the reverse link signal, the slave base station adjusts its timing so that the mobile station can acquire its signal, referred to as a forward link signal. This step may be unnecessary if the timing error in the slave base station is not severe.

Once the mobile station acquires the signal from the slave base station, it measures and reports the difference between the amount of time it takes a signal to travel from the reference base station to it and the amount of time it takes a signal to travel from the slave base station to it. The last measurement necessary is a measurement by the slave base station of the time difference between the time it received the reverse link signal from the mobile and station the time it transmitted a signal to the mobile station.

A series of computations described in detail herein are performed upon the measured time values to determine the time difference between the slave base station and an adjustment of the slave base station timing is performed in accordance therewith. It should be noted that all of the measurements mentioned are performed during the normal operation of an IS-95 CDMA communication system.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is a block diagram illustrating the network configuration of a wireless communication system comprising a reference base station and a slave base station;

FIG. 2 is a diagram illustrating the various transmissions between the mobile station, the synchronous base station and the asynchronous base station and the corresponding time intervals;

FIG. 3 is a flowchart illustrating the method for synchronizing a base station which is incapable of receiving a centralized timing signal;

FIG. 4 is a block diagram of the mobile station of the present invention;

FIG. 5 is a block diagram of the searcher in the mobile station of the present invention;

FIG. 6 is a block diagram of the traffic channel modulator of the mobile station of the present invention;

FIG. 7 is a block diagram of the base station of the present invention;

FIG. 8 is a block diagram of transmission system of the base station of the present invention; and

FIG. 9 is a block diagram of receiver system of the base station of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. Overview of Timing Error Computation

Referring to FIG. 1, mobile station **60** is in communication with base station **62**, while it is roughly within the coverage area delineated by base station coverage boundary **61**. Base station **62** is synchronized to the rest of the network by means of a central timing system such as the global positioning system (GPS). In contrast, base station **64** is not synchronized to the central timing system. Base station controller **66** routes calls from the PSTN to a base station **62** or **64** by means of a T1 line or other means. In

addition, frequency synchronization is provided to base station 64 through T1 lines.

For short time periods, frequency synchronization can be provided with an acceptable degree of accuracy through T1 lines by methods well known in the art. However, glitches are common in these schemes for providing frequency information. These glitches result in timing errors which can be corrected by use of the present invention. Because of the relationship between phase and frequency, the present invention's intermittent correction of phase will permit the utilization of a less accurate frequency sources when necessary.

Referring to FIG. 2, an illustration of the transmission and corresponding time intervals used to synchronize the timing of slave base station 64 with the synchronized timing of reference base station 62. Signal path 500 illustrates the transmission of a forward link signal from reference base station 62 to mobile station 60. The time interval over which this transmission occurs is designated as τ_1. At mobile station 60, the start of frame transmissions on the reverse link are time aligned with the start of frame arrivals on the forward link. This time alignment is standardized in IS-95 and incorporated in hardware designed in conformance therewith such that methods and apparatus for performing this alignment are well known in the art.

Transmission 502 depicts the transmission of a reverse link frame from mobile station 60 to reference base station 62. The time for a signal 500 to travel from base station 62 to mobile station 60 (τ_1) is equal to the time for signal 502 to travel from base station 62 to mobile station 60 (also τ_1). Because base station 62 knows the time at which it transmitted signal 500 and knows the time at which it received signal 502, base station 62 can compute the round trip delay time (RTD_1), which is the first value necessary in the computation of the time error ($\tau_0'-\tau_0$).

Signal path 504 is the reverse link signal transmission from mobile station 60 traveling along a different propagation path to slave base station 64. The time which it takes signal 504 to travel from mobile station 60 to slave base station 64 is designated as τ_2. The time at which the reverse link signal 504 reaches base station 64 is designated as T_2. The time it takes a forward link signal 506 traveling from base station 64 to mobile station 60 is also equal to τ_2. In addition, slave base station 64 can measure the time difference between the time it received the reverse link signal from mobile station 60 and the time it transmitted its forward link signal to mobile station 60. This time difference is designated as RTD_2. Knowing

these times allows for the computation of the time error ($\tau_0'-\tau_0$).The method for computing the time error τ_0' is described below.

First it can be observed from FIG. 2 that:

$$T_2 = \tau_1 + \tau_2, \text{ and} \quad (1)$$

$$\tau_1 + \Delta T = T_0' + T_2 \quad (2)$$

By manipulating the terms of equations (1) and (2), the following is observed:

$$T_2 + \Delta T = T_0' + 2\cdot\tau_2 \quad (3)$$

$$2\cdot\tau_2 = T_2 - T_0' + \Delta T \quad (4)$$

To simplify the notation, a new variable RTD_2 is defined as:

$$RTD_2 = T_2 - T_0' \quad (5)$$

It can be seen from FIG. 2 that:

$$\tau_2 = \frac{RTD_2}{2} + \frac{\Delta T}{2} \quad (6)$$

$$T_2 = T_0 + \tau_1 + \tau_2 \quad (7)$$

Therefore,

$$T_2 - T_0 = \tau_1 + \tau_2, \text{ and} \quad (8)$$

$$RTD_2 = 2\cdot\tau_2 - \Delta T$$

By substitution, it can be seen that the time error ($T_0' - T_0$) is equal to:

$$T_0' - T_0 = \tau_1 - \tau_2 + \Delta T \quad (9)$$

$$T_0' - T_0 = \tau_1 - \left[\frac{RTD_2}{2} + \frac{\Delta T}{2}\right] + \Delta T \quad (10)$$

$$T_0' - T_0 = \frac{RTD_1}{2} - \frac{RTD_2}{2} + \frac{\Delta T}{2} \quad (11)$$

$$T_0' - T_0 = \frac{RTD_1 + \Delta T - RTD_2}{2} \quad (12)$$

Once base station 64 knows the amount of its timing error ($T_0' - T_0$), it adjusts its timing so as to synchronize it to the timing of base station 62.

These measurements are subject to error, so, in a preferred embodiment, many of the measurements are redundantly made to assure the accuracy of the timing correction.

The method and apparatus for measuring each of the necessary time values in equation (12) is now described.

II. Measurement of Round Trip Delay (RTD_1)

FIG. 3 is a flow diagram illustrating the method of the present invention for synchronizing slave base station 64 to the timing of reference base station 62. In step 300, the synchronization method commences, with mobile station 60 in communication with reference base station 62 and within range to conduct communications with slave base station 64. In step 302, the round trip delay (RTD_1) time for a signal to travel from reference base station 62 to mobile station 60 and back from mobile station 60 to reference base station 62 is measured. This is done by aligning the frame boundaries of frames being received by mobile station 60 with the frame boundaries of frames being transmitted by mobile station 60. The method and apparatus for providing this alignment is well known in the art. Thus, the round-trip delay (RTD_1) is measured as the time difference between the start of frames transmitted by reference base station 62 and the start of frames received by reference base station 62 from mobile station 60.

Referring to FIG. 4, forward link frames of data from reference base station 62 are received at antenna 2 and provided through duplexer 3 to receiver (RCVR) 4. Receiver 4 downconverts, filters and amplifies the received signal and provides it to searcher 50 and traffic demodulators (TRAFFIC DEMODS) 54. Searcher 50 searches for pilot channels in accordance with a neighbor list provided by reference base station 62. The neighbor list is provided as signaling data on the traffic channel from reference base station 62. A signal indicating the start of received frames from reference base station 62 is provided to control processor 55. Control processor 55 generates and provides a time alignment signal to traffic modulator 58 which aligns the start of frames transmitted from mobile station 60 with the start of frames received at mobile station 60.

Frames of data from the user of mobile station 60 are provided to traffic modulator 58 which in response to the timing signal from control processor 55 time aligns the frames transmitted through transmitter (TMTR) 56 with the frames received by mobile station 60 from reference base station 62. The reverse link frames are upconverted, filtered and amplified

by transmitter 56 then provided through duplexer 3 for transmission through antenna 2.

III. Acquisition of Mobile Station by Slave Base Station

FIG. 6 illustrates the traffic channel modulator 58 of mobile station 60. Frames of data are provided to frame formatter 200. In the exemplary embodiment, frame formatter 200 generates and appends a set of cyclic redundancy (CRC) check bits and generates a set of tail bits. In the exemplary embodiment, frame formatter 200 follows the frame format protocol standardized in IS-95 and described in detail in U.S. Patent No. 5,600,754, entitled "METHOD AND SYSTEM FOR THE ARRANGEMENT OF VOCODER DATA FOR THE MASKING OF TRANSMISSION CHANNEL INDUCED ERRORS", which is assigned to the assignee of the present invention and incorporated by reference herein.

The formatted data frame is provided to encoder 202 which encodes the data for error correction and detection. In the exemplary embodiment, encoder 202 is a convolutional encoder. The encoded data symbols are provided to interleaver 204 which reorders the symbols in accordance with a predetermined interleaving format. The reordered symbols are provided to Walsh mapper 206. In the exemplary embodiment, Walsh mapper 206 receives eight coded symbols and maps that set of symbols to a 64 chip Walsh sequence. The Walsh symbols are provided to spreading means 208 which spreads the Walsh symbols in accordance with a long spreading code. Long PN code generator 210 generates a pseudonoise (PN) sequence that spreads the data and differentiates the data from the reverse link transmitted data from other mobile stations in the vicinity.

In the exemplary embodiment, the data is transmitted in accordance with a quaternary phase shift keying (QPSK) modulation format wherein the I and Q channels are spread in accordance with a short PN sequence. The spread data is provided to spreading means 214 and 216 which perform a second spreading operation on the data in accordance with a short PN sequence provided by PN generators (PN_I and PN_Q) 212 and 218 respectively.

In step 304, slave base station 64 acquires the reverse link signal transmitted by mobile station 60. Base station controller 66 sends a signal to slave base station 64 indicating the PN code offset which mobile station 62 is using to spread its reverse link signal. In response to this signal from base station controller 66, slave base station 64 performs a search for the mobile

station 60 centered about the PN offset indicated by the signal from base station controller 66.

In the exemplary embodiment, slave base station 64 bank loads its searchers long code PN generator 106 and its short code PN generators 108 and 110 (illustrated in FIG. 9) in accordance with a signal from base station controller 66. The searcher process of slave base station 64 is described in detail further herein.

FIG. 7 illustrates the apparatus of slave base station 64. In slave base station 64, a signal from base station controller 60 indicating the PN of mobile station 60 is received. This message is provided to by control processor 100. In response thereto, control processor 100 computes the window search range centered at the specified PN offset. Control processor 100 provides the search parameters to searcher 101 and in response to those parameters slave base station 64 conducts a search for the signal transmitted by mobile station 60. The signal received by antenna 102 of slave base station 64 is provided to receiver 104 which downconverts, filters and amplifies the received signal and provides it to searcher 101. In addition, the received signal is provided to traffic demodulators 105 which demodulate the reverse link traffic data and provide that data to base station controller 60. Base station controller 66, in turn provides it to a public switched telephone network (PSTN).

FIG. 9 illustrates searcher 101 in greater detail. The demodulation of the reverse link signal is described in detail in co-pending U.S. Patent Application Serial No. 08/372,632, filed January 13, 1995, entitled "CELL SITE DEMODULATOR ARCHITECTURE FOR A SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM" and in co-pending U.S. Patent Application Serial No. 08/316,177, filed September 30, 1994, entitled "MULTIPATH SEARCH PROCESSOR FOR A SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM", both of which are assigned to the assignee of the present invention and incorporated by reference herein. An estimate of the PN offset of mobile station 60 is provided to control processor 100 from base station controller 66. In response to the PN offset estimation provided by base station controller 60, control processor 100 generates an initial long PN sequence hypothesis and an initial short PN sequence hypothesis for the search to be performed by slave base station 64. In the exemplary embodiment, control processor 100 bank loads the shift registers of PN generators 106, 108 and 110.

The signal is received by antenna 102 is downconverted, filtered and amplified and passed to correlator 116. Correlator 116 correlates the received

signal to the combined long and short PN sequence hypothesis. In the exemplary embodiment, the PN sequence hypothesis is generated by multiplying the short PN hypotheses generated by PN generators **108** and **110** by the long PN sequence generated by PN generator **106**. One of the combined PN sequence hypotheses is used to despread the I channel and the other is used to despread the Q channel of the received QPSK signal.

The two PN despread signals are provided to fast Hadamard transform (FHT) processors **118** and **120**. The design and operation of fast Hadamard transform processors is described in detail in co-pending U.S. Patent Application Serial No. 08/173,460, filed December 22, 1993, entitled "METHOD AND APPARATUS FOR PERFORMING A FAST HADAMARD TRANSFORM", which is assigned to the assignee of the present invention and incorporated by reference herein. FHT processors **118** and **120** correlate the despread signals with all possible Walsh symbols to provide a matrix of the resultant amplitudes to energy computation means (I^2+Q^2) **122**. Energy computation means **122** computes the energy of the amplitude matrix elements and provides the energy values to max detector **124** which selects the maximum energy correlation. The maximum correlation energies are provided to accumulator **126** which accumulates the energies for a plurality of Walsh symbols and based upon these accumulated energies, a decision is made as to whether the mobile station **60** can be acquired at that PN offset.

IV. Initial Timing Adjustment by Slave Base Station

Once mobile station **60** is acquired, then, in block **306**, slave base station **64** adjusts its timing so that mobile station **60** will be able to successfully acquire its forward link transmissions. Slave base station **64** computes an initial timing adjustment by determining the difference between the PN offset at which it acquired the reverse link signal from mobile station **60** and the PN offset which reference base station **62** used for reception of the reverse link signal from mobile station **60**. Using this PN offset difference, slave base station **64** adjusts the timing of its pilot signal in such a way that when mobile station **60** searches for its pilot signal it will be within the search window of mobile station **60**.

V. Acquisition of the Slave Base Station by the Mobile Station

In searching for the mobile station signal, it is necessary for slave base station **64** to have some indication of time. In the preferred embodiment,

the time error of slave base station 64 is kept at or below 1 ms by means of an alternative synchronization scheme. There are schemes which enable slave base station 64 which is incapable of receiving a GPS signal to keep time to a level of lesser precision. One possible method of obtaining a degree of initial synchronization is to manually set the time of slave base station 64 at certain intervals. A second method is to set the time using a WWV receiver, the implementation of which is well known in the art. Unlike the GPS signal, the WWV centralized timing signal is transmitted at very low frequency and is able to penetrate into tunnels and subways. However, WWV receivers are not capable of providing the degree of time synchronization necessary for providing CDMA communications.

In the exemplary embodiment, slave base station 64 adjusts its timing in accordance with the assumption that mobile station 60 is located directly adjacent to slave base station 64. Thus, the initial timing adjustment is made under the hypothesis that there will be no propagation delay between slave base station 64 and mobile station 60. Thereafter, slave base station 64 adjusts its PN sequence generators 72 and 74 forward in time which accounts for greater and greater propagation delay times between slave base station 64 and mobile station 60. Once mobile station 60 has acquired the pilot channel of slave base station 64, using normal procedures the final adjustment of timing for slave base station 64 can be performed in accordance with the computations described above.

As is known in the art and standardized in IS-95, pilot channels of different base stations are distinguished from one another by the phase of their PN generators. Reference base station 62 instructs mobile station 60 to search for slave base station 64 via the neighbor list. Reference base station 62 indicates by means of the signaling data that the pilot of slave base station 64 can be acquired at a PN phase offset which is described relative to the received PN offset of reference base station 62. This message is demodulated and decoded by traffic demodulators 54 and provided to searcher 50. In response, searcher 50 performs a search centered on a PN phase offset about the PN phase indicated in the signal from reference base station 62.

The pilot signal is typically generated by a linear feedback shift register, the implementation of which is described in detail in the aforementioned patents. In order to acquire the pilot signal from slave base station 64, mobile station 60 must synchronize to the received signals from slave base station 64 in both phase, ϕ, and in frequency, ω. The object of the searcher operation is to find the phase of the received signal, ϕ. As described earlier, a relatively accurate frequency synchronization can be supplies to

slave base station 64 by means of a T1 link from base station controller 66 as is known in the art. The method by which a mobile finds the phase of the received signal is by testing a set of phase hypotheses, referred to as a search window and determining if one of the offset hypotheses is correct.

FIG. 5 illustrates mobile station searcher 50 in greater detail. A spread spectrum signal is received at antenna 2. The objective of the apparatus is to gain synchronization between pseudorandom noise (PN) sequences generated by PN sequence generator 20 and the received spread spectrum signal which is spread by identical PN sequences of unknown phase transmitted by slave base station 64. In the exemplary embodiment, both pilot signal generator 76 (of FIG. 7) and PN generator 20 are maximal length shift registers which generate the PN code sequences for spreading and despreading the pilot signals respectively. Thus, the operation of obtaining synchronization between the codes used to despread the received pilot signal and the PN spreading code of the received pilot signal involves determining the time offset of the shift register.

The spread spectrum signal is provided by antenna 2 to receiver 4. Receiver 4 downconverts, filters and amplifies the signal and provides the signal to despreading element 6. Despreading element 6 multiplies the received signal by the PN code generated by PN generator 20. Due to the random noise like nature of the PN codes, the product of the PN code and the received signal should be essentially zero except at the point of synchronization.

Searcher controller 18 provides an offset hypothesis to PN generator 20. The offset hypothesis is determined in accordance with a signal transmitted to mobile station 60 by reference base station 62. In the exemplary embodiment, the received signal is modulated by quaternary phase shift keying (QPSK), so PN generator 20 provides a PN sequence for the I modulation component and a separate sequence for the Q modulation component to despreading element 6. Despreading element 6 multiplies the PN sequence by its corresponding modulation component and provides the two output component products to coherent accumulators 8 and 10.

Coherent accumulators 8 and 10 sum the product over the length of the product sequence. Coherent accumulators 8 and 10 are responsive to signals from searcher controller 18 for resetting, latching and setting the summation period. The sums of the products are provided from summers 8 and 10 to squaring means 14. Squaring means 14 squares each of the sums and adds the squares together.

The sum of the squares is provided by squaring means **12** to noncoherent combiner **14**. Noncoherent combiner **14** determines an energy value from the output of squaring means **12**. Noncoherent accumulator **14** serves to counteract the effects of a frequency discrepancy between the base station transmit clocks and the mobile station receive clock and aids in the detection statistic in a fading environment. Noncoherent accumulator **14** provides the energy signal to comparison means **16**. Comparison means **16** compares the energy value to predetermined thresholds supplied by searcher controller means **18**. The results of each of the comparisons is then feedback to searcher controller **18**. The results fedback to searcher controller **18** include both the energy of the correlation and the PN offset that resulted in the measurement.

In the present invention, searcher controller **18** outputs the PN phase at which it synchronized to base station **64**. This offset is used to compute the time error as described further herein.

In the exemplary embodiment, when mobile station **60** acquires slave base station **64** it computes the difference between the time it received the signal from slave base station **64** and the time it received the signal from reference base station **62**. This value is provided to message generator **52** which generates a message indicative of the difference value. The message is transmitted as signaling data on the reverse link to reference base station **62** and slave base station **64** which send the message back to base station controller **66**.

VI. Measurement of Delay Between Transmission of Forward Link Signal From Slave Base Station and Receipt of Reverse link Signal at Slave Base Station

In step **311**, slave base station **64** measures the time difference between it received the reverse link signal from mobile station **60** (T_2) and the time it transmitted its forward link signal to mobile station **60** (T_1). Slave base station **64** stores the PN offset at the time it transmits its forward link signal and upon detection of the reverse link signal from mobile station **60** computes the time difference RTD_2. In the exemplary embodiment, this computed time difference is provided by slave base station **64** to base station controller **66** and the computation of the timing adjustment is conducted at base station **66**. It will be understood by one skilled in the art that the present invention is easily extended to the case wherein the computations are performed at the base stations or mobile stations.

VII. Timing Adjustment of Slave Base Station

Base station controller **66**, in response, performs the computation described in equation (12) and sends an indication of the necessary timing adjustment to slave base station **64**. Referring back to FIG. 7, the timing adjustment signal is received by slave base station **64** at control processor **100**. Control processor **100** generates and provides a control signal to timing adjustment processor **99**. Timing adjustment processor **99** generates a signal which changes the time of timing source **98** by the amount indicated in the signal from base station controller **66**.

WE CLAIM:

CLAIMS

1. A method for time synchronizing a first base station with a reference base station comprising the steps of:

measuring a round trip delay interval of transmissions from said reference base station to a mobile station in communication with said reference base station and back from said mobile station to said reference base station;

measuring at said mobile station a first time difference between the time of receipt of a forward link signal from said first base station and the time of receipt of a forward link signal from said reference base station;

measuring at said slave base station a second time differences between the receipt of a reverse link signal from said mobile station and the time of transmission of a forward link signal from said first base station; and

computing a timing correction value in accordance with said measured round trip delay interval, said first time difference and said second time difference.

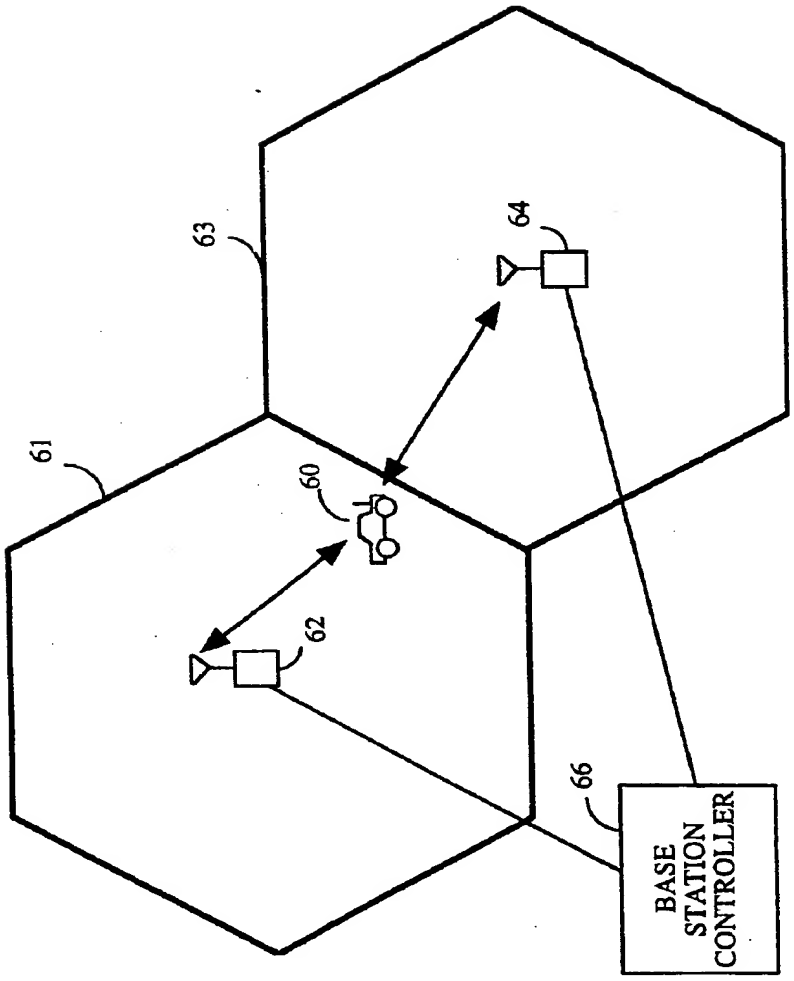

FIG. 1

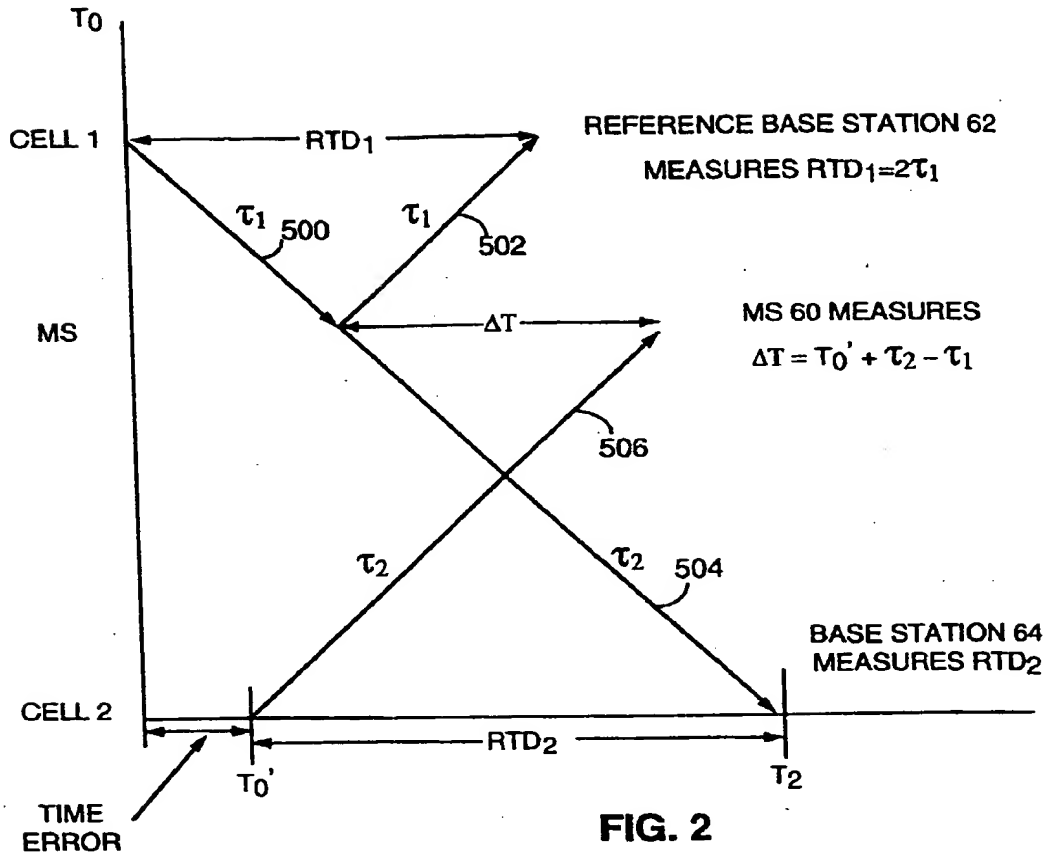
T0
CELL 1
RTD1
REFERENCE BASE STATION 62
MEASURES RTD1=2τ1
τ1
500
τ1
502
MS
ΔT
MS 60 MEASURES
ΔT = T0' + τ2 – τ1
506
τ2
τ2
504
BASE STATION 64
MEASURES RTD2
CELL 2
RTD2
T0'
T2
TIME
ERROR

FIG. 2

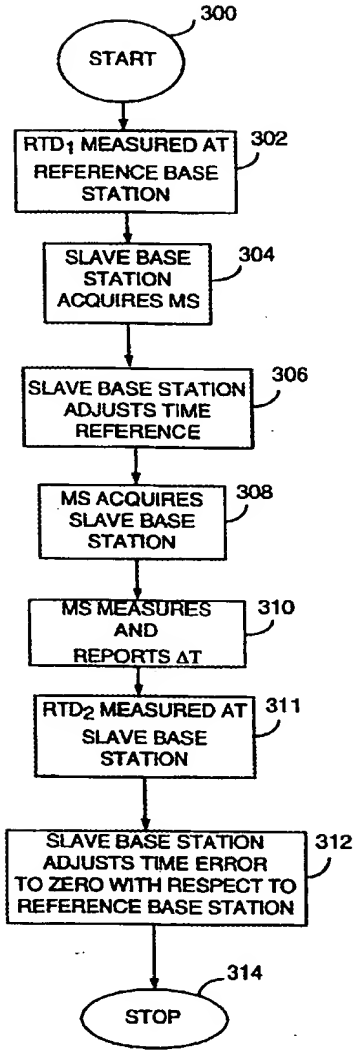
300
START
RTD1 MEASURED AT REFERENCE BASE STATION
302
SLAVE BASE STATION ACQUIRES MS
304
SLAVE BASE STATION ADJUSTS TIME REFERENCE
306
MS ACQUIRES SLAVE BASE STATION
308
MS MEASURES AND REPORTS ΔT
310
RTD2 MEASURED AT SLAVE BASE STATION
311
SLAVE BASE STATION ADJUSTS TIME ERROR TO ZERO WITH RESPECT TO REFERENCE BASE STATION
312
314
STOP

FIG. 3

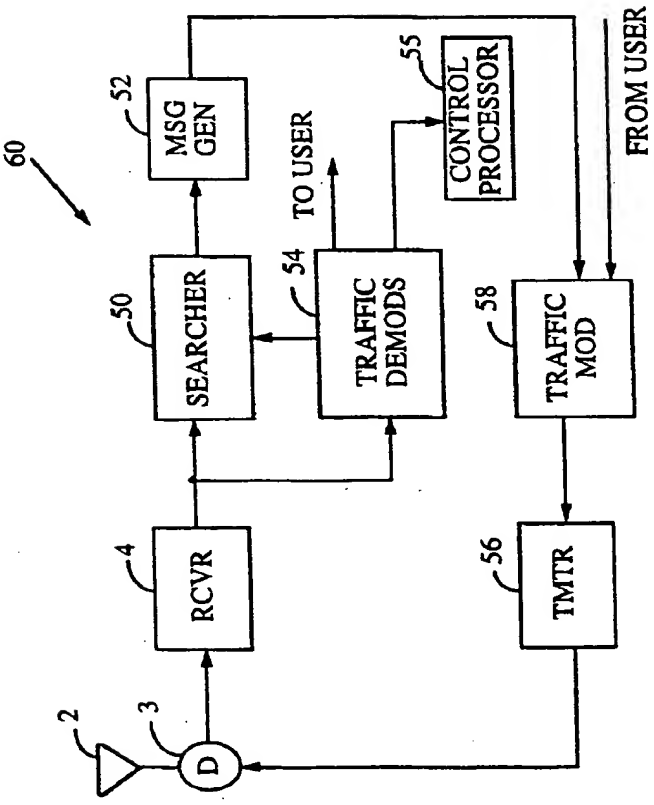
60
2
3
D
4
RCVR
50
SEARCHER
52
MSG GEN
54
TRAFFIC DEMODS
TO USER
55
CONTROL PROCESSOR
56
TMTR
58
TRAFFIC MOD
FROM USER

FIG. 4

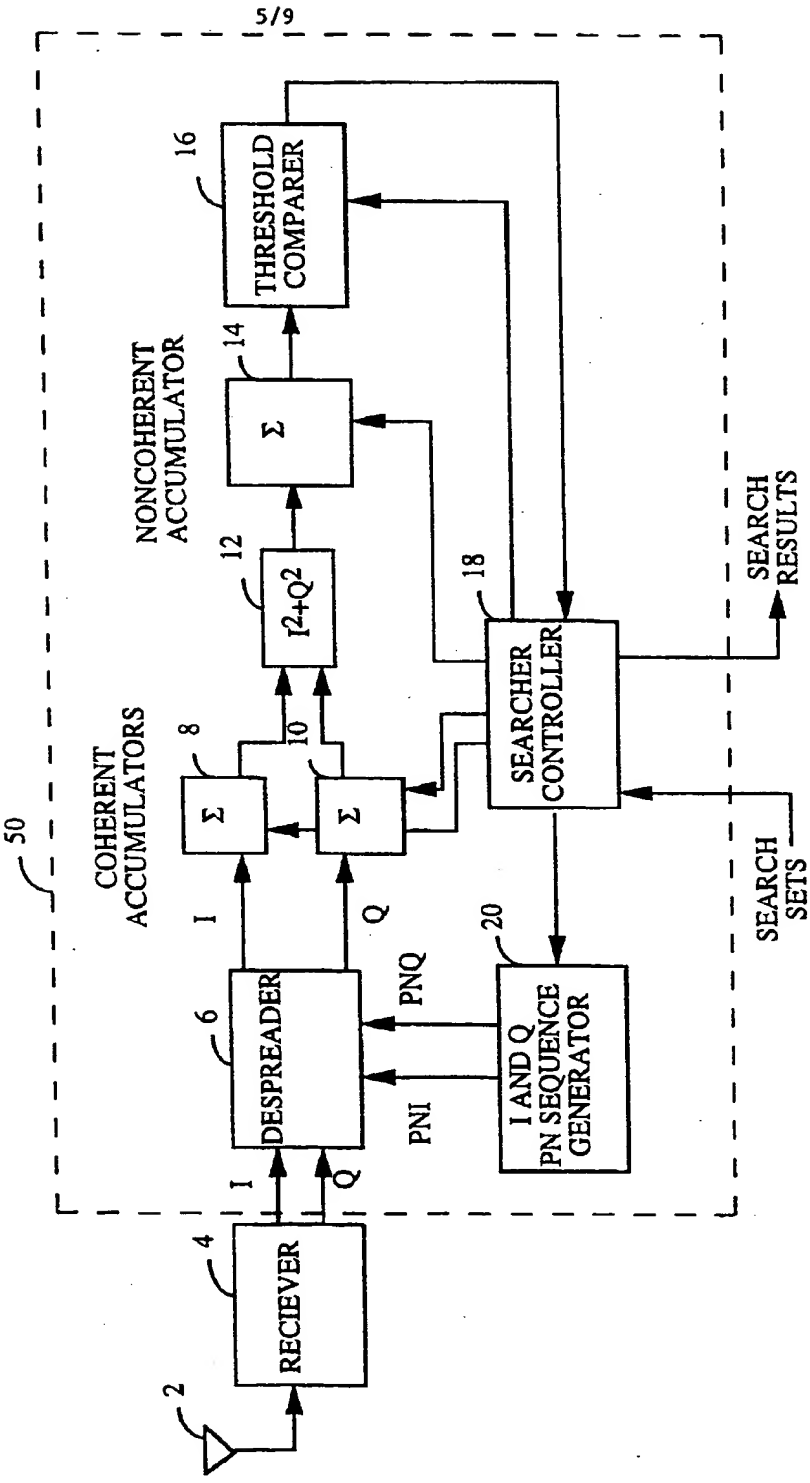
50
COHERENT ACCUMULATORS
NONCOHERENT ACCUMULATOR
2
4
RECIEVER
6
DESPREADER
8
Σ
10
Σ
12
I2+Q2
14
Σ
16
THRESHOLD COMPARER
18
SEARCHER CONTROLLER
20
I AND Q PN SEQUENCE GENERATOR
I
Q
I
Q
PNI
PNQ
SEARCH RESULTS
SEARCH SETS

FIG. 5

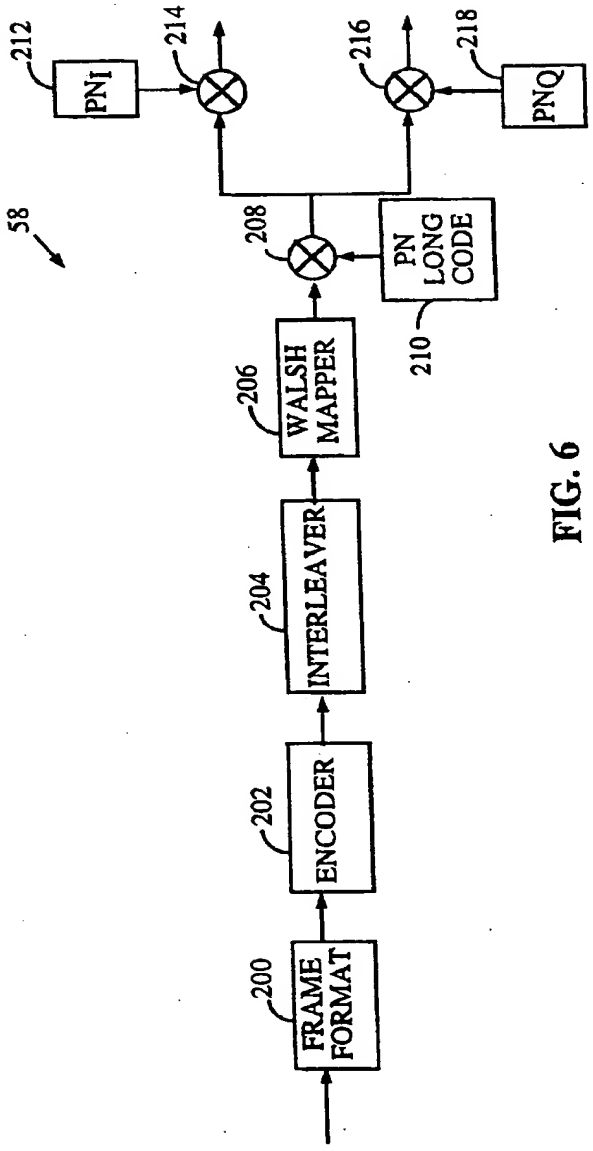
58
200
FRAME FORMAT
202
ENCODER
204
INTERLEAVER
206
WALSH MAPPER
208
210
PN LONG CODE
212
PNI
214
216
218
PNQ

FIG. 6

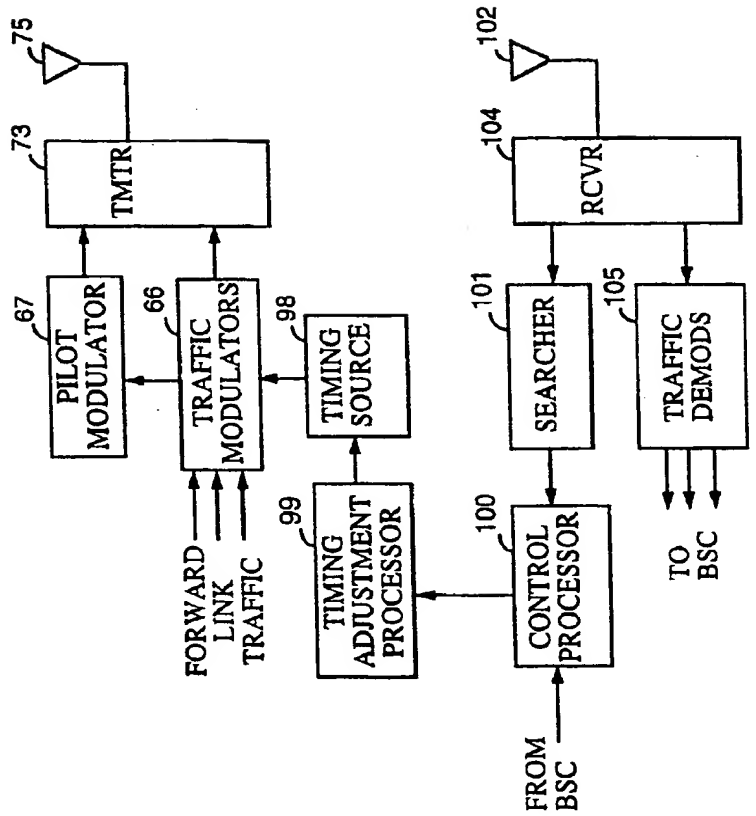
75
73
TMTR
67
PILOT MODULATOR
66
TRAFFIC MODULATORS
98
TIMING SOURCE
99
TIMING ADJUSTMENT PROCESSOR
FORWARD LINK TRAFFIC
102
104
RCVR
101
SEARCHER
105
TRAFFIC DEMODS
100
CONTROL PROCESSOR
TO BSC
FROM BSC

FIG. 7

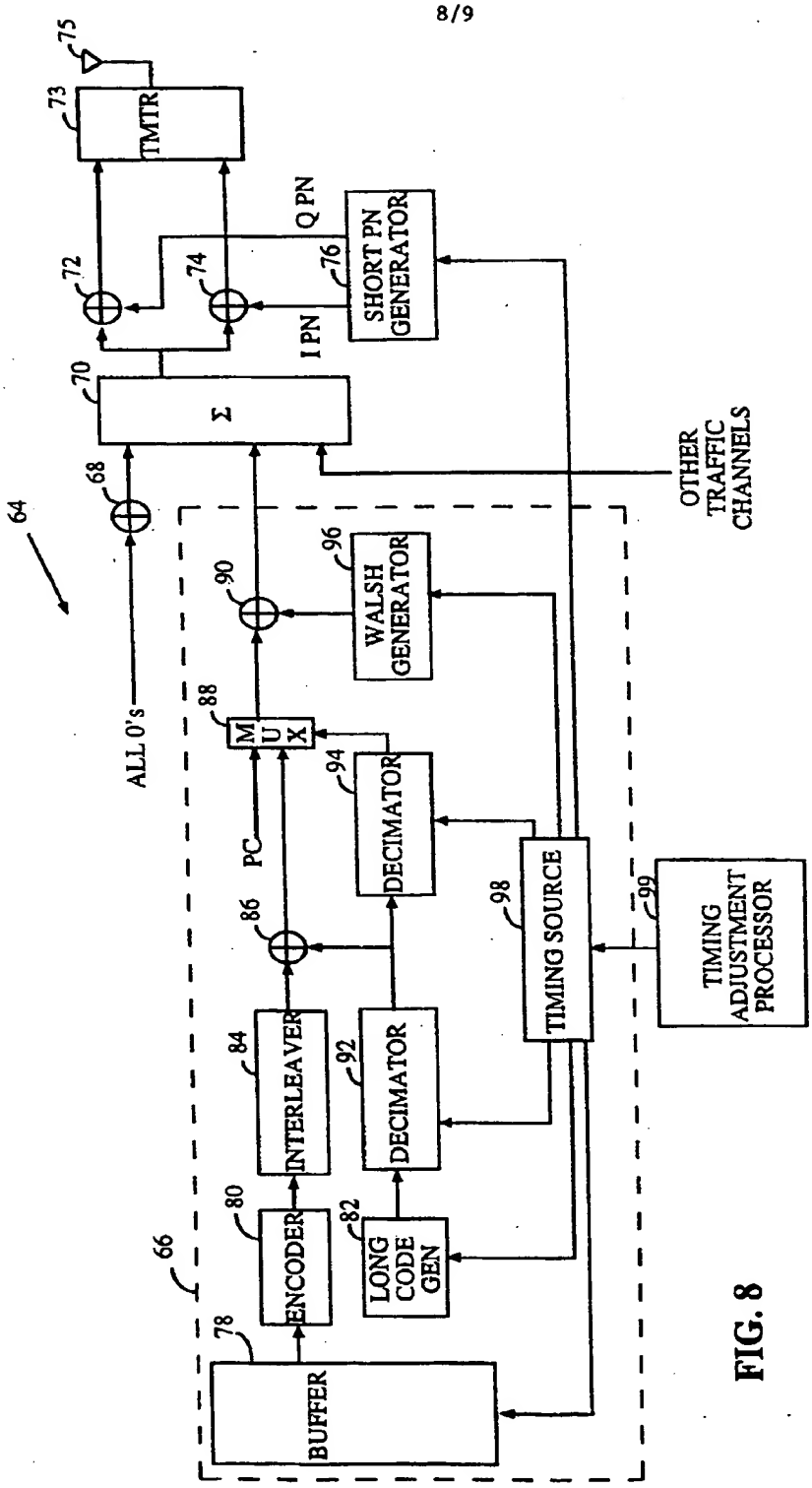
75
73
TMTR
Q PN
72
74
76
SHORT PN GENERATOR
I PN
70
Σ
OTHER TRAFFIC CHANNELS
68
64
96
WALSH GENERATOR
90
88
M U X
ALL 0's
PC
94
DECIMATOR
86
98
TIMING SOURCE
99
TIMING ADJUSTMENT PROCESSOR
84
INTERLEAVER
92
DECIMATOR
80
ENCODER
82
LONG CODE GEN
66
78
BUFFER

FIG. 8

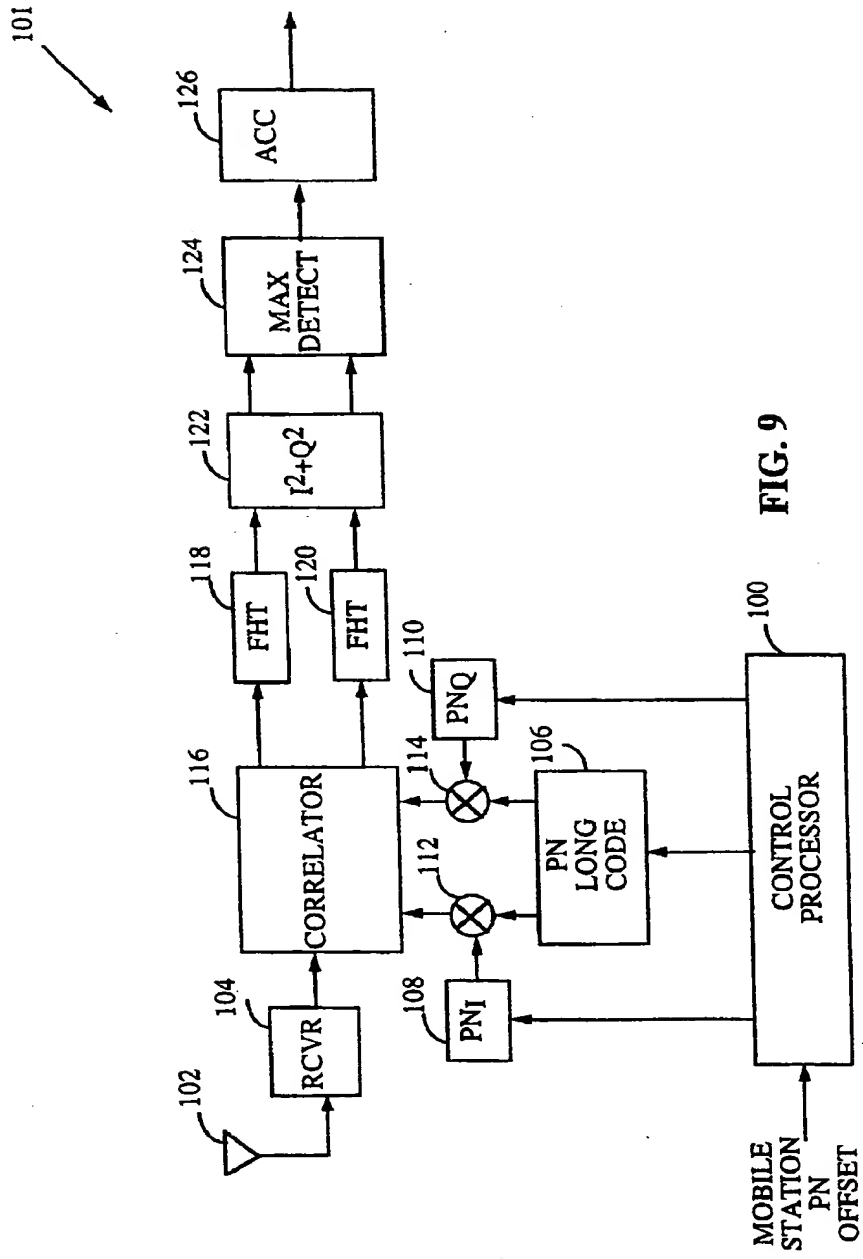
101
126
ACC
124
MAX DETECT
122
I2+Q2
118
FHT
120
FHT
110
PNQ
116
CORRELATOR
114
106
PN LONG CODE
112
100
CONTROL PROCESSOR
104
RCVR
108
PNI
102
MOBILE STATION PN OFFSET

FIG. 9